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TECHNICAL REPORT

HIGH TEMPERATURE RESISTANCE THERMOMETER TEMPERATURE CONTROLLER

BY

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ABSTRACT

A low resistance thermometer temperature controller was constructed, consisting of a sensing element, a wheatstone bridge unit, a galvanometer with capacitor "flag", a "Thermocap Relay", a regulating reactor and power contactors. The sensitivity may be adjusted so that temperatures can be maintained with only $\pm$ 1°C. fluctuation within the range of 200° to 1500°C.

INTRODUCTION

In the study of metal-ceramic mixtures at elevated temperatures a need arose for a furnace which would make possible the loading and unloading of a specimen in an atmosphere other than air. The furnace designed for this purpose has been described by H. I. Sephton[1] and is shown in figure 1. The automatic temperature controller mentioned in that paper is described more completely here to reveal its construction and operation. The temperature controller was constructed to: Regulate the temperature in an atmosphere type furnace with the temperature sensing element surrounding the temperature and atmosphere control zone; Summarize temperature over a region rather than at a point; Maintain the temperature with very small fluctuations over extended periods of time.

This unit is designed as a constant temperature controlling circuit, which may be used in much the same manner as any temperature control unit. This is, it incoorperates a sensing element, transmission system and receiving and controlling circuit which is coupled into the power circuit by a regulating reactor and relay type control system. Consequently this temperature control system might be used on industrial as well as laboratory type equipment.

CONSTRUCTION DETAILS

The controller has been separated into the following component parts for convenience of discussion: sensing element, wheatstone bridge unit, galvanometer with capacitor flag, "Thermocap Relay", regulating reactor and power contactors.

Sensing Element:

The resistance thermometer element has long been accepted as one of the most precise temperature sensing devices, especially in the temperature range below 1100°C.[2] Use of platinum or platinum-rhodium elements above this range is quite feasible; however, it is necessary to know the behavior of the elements at these temperatures.

The sensing element consists of six feet of number 20 B & S gage 80% platinum - 20% rhodium wire. The ratio of resistance at 1000°C. to that at 900°C. is 1.06, for this element having 0.0006 ohms/°C. change over this range. The wire was annealed, then bifilar wound on the "impervious" furnace muffle for a distance of 1½ inches around the control temperature zone of the muffle. The wire was then coated with a 1/16 inch thickness of Norton RA 1139 refractory cement. The ends of the wire were brought out of the furnace to a point where large banana plugs were connected to the lead wires of the wheatstone bridge unit.

Wheatstone Bridge Unit:

The components of the bridge are arranged in the manner shown in figure 2. This unit is a low resistance wheatstone bridge. In the low resistance side, the cold-to-hot resistance of the sensing element (approximately 0.5 to 1.5 ohms) is compared to a one ohm fixed resistor. On the higher resistance side of the bridge, a 25 ohm ten turn, "Helipot" control plus 15 ohms of series resistance, is compared to either a fixed resistor of 25 ohms, on the high range, or 30 ohms on the low temperature range.

The Helipot control thus can be empirically calibrated to match the temperature of the sensing element. The element covers about one degree for each of its one thousand dial divisions;- in two ranges of approximately 30-100 and 500-1500°C.

The bridge is powered by a single lead plate storage cell. This cell furnishes 2 volts d.c. at the required 1-2 amperes. It is placed on a glass or equivalent insulating sheet which is kept clean of any possible acid creepage. The cell may be continuously connected to a trickle type charger, or eliminated entirely by a suitable a.c. operated d.c. supply, provided adequate insulation to ground or a.c. line is maintained. Leakage resistance to ground or line

must be at least one megohm to avoid temperature error. Reduction of d.c. supply voltage will increase width of neutral zone and decrease sensitivity, but will not affect actual temperature settings.

The bridge unit is placed as closely as possible to the banana plug connections of the sensing element, and connected by short heavy wire to minimize unwanted resistance variation in this leg of the bridge.

When the element temperature is matched by the equivalent Helipot setting, the current output of the bridge is zero. The output increases about 0.1 micro-ampere per degree difference, with polarity depending on the direction of the temperature variation. This output current passes through a 5000 ohm sensitivity control to a galvanometer having capacity pick-up plates.

Galvanometer with Capacitor:

In many phases of electrical measurement the galvanometer has remained as the only "bottle neck" in precise control. One of the principle reasons for the galvanometer being unsatisfactory is the necessity of using mechanical attachments on the output stage. As a consequence, time lags are introduced, making high degrees of sensitivity virtually impossible. This situation has led to either complete replacement of the galvanometer by electronic systems or substitution of non-mechanical coupling devices on the galvanometer such as photoelectric, induction or capicator pick-ups.[3] This instrument eliminates mechanical contacts on the galvanometer by using a capacitance pick-up system.

A Weston Model 440 No. 7295 galvanometer is used having a coil resistance of 153 ohms. A capacitor pick-up is placed on the rear (counter balance) end of the pointer assembly. The weight of the pick-up plate is balanced by adding weight, as necessary, to the pointer end. The pick-up "flag" is 3/16 inches square. Copper "U" shaped sheets approximately twice this size spaced 1/16 inch apart form the secondary portion of the capacitor pick-up system. This assembly is attached to the rear of the galvanometer case and in turn to the "Thermocap Relay" unit by a very short lead of small

copper wire, requiring the galvanometer to be set on top of the relay unit. The use of the "U" shaped secondary portion of the capacitor pick-up system eliminates small fluctuations in capacitance caused by variations in portions of the flag relative to the pick-up device.

Thermocap Relay:

This unit is a sensitive capacity operated relay made by the Niagara Electron Laboratories of Andover, New York. The model incorporated in this control is a dual relay type (on-off-on) as mentioned on page 14 of Bulletin T 3/9-51, Niagara Electron Laboratories.

The Thermocap is equipped with two output contactors which operate as follows:

Condition "A":-Capacity (and temperature) below set point results in both output contacts being closed.

Condition "B":-Capacity at set point results in one output contact being closed and the other open.

Condition "C":-Capacity above set point results in both contacts being open.

The sensitivity of the galvanometer - Thermocap combination is such that a change of $\pm$ one degree on the sensing element is sufficient to swing control from condition "A" to condition "C" or vice versa. However, the movement (temperature difference) required by the galvanometer needle to charge the relays to any adjacent set of conditions, such as from A to B, is approximately one tenth this amount of swing, or one tenth of a millimeter.

Regulating Reactor and Power Contactors:

The output contacts of the Thermocap are utilized as automatic switches to control two external power contactors, which short out selected portions of a multi-tapped reactor. This reactor is placed in series on the line side of the transformer which furnishes power to the Globar heaters in the furnace.

OPERATION

Figure 2 is a schematic drawing of the control circuit with the power supply circuit. The following steps set forth the principle of operation of the control circuit.

1. The temperature is first assumed to be at the set point, within neutral zone of control. One contactor is closed, shorting out sufficient reactance to allow passage of sufficient current to approximate normal demand.

2. If the temperature drops below this range, resistance of the sensing element is decreased. The wheatstone bridge then becomes unbalanced, resulting in a deflection of the galvanometer in the direction to produce less capacity in the Thermocap circuit.

3. This reduction in capacity actuates the Thermocap so that the second contactor also closes, shorting out further reactance, and thereby increasing heat to the furnace.

4. As the temperature then rises in the furnace, the control coil senses the increase immediately by radiational means and increases its resistance. This operates the entire control system in the reverse direction of step #2 above, and restores the condition of step #1, with only one contactor closed.

5. Should, however, the rise go too far and go above the neutral zone, the galvanometer deflects in the direction of increasing capacity. The Thermocap then opens the first contact, placing the full reactance in series with the transformer. This produces the necessary decrease in heat to return the temperature to the set point.

Because the temperature control coil is positioned between the heating element and the specimen, it requires a very small fluctuation in power supplied to the heating elements with a subsequent small change in temperature to be sensed by the control coil. Also because of the distance involved from the heating elements to the control coil, and because of the finite heat capacity of the system,

the specimen located at the central point within this arrangement experiences but a small fraction of the temperature variation obtained on the heating element. This situation has been established by placing a standard bare thermocouple at this location and making temperature measurements by the use of a precision portable potentiometer. Variations of $\pm$ 1°C. over the temperature range between 200 - 1500°C. were obtained.

MANIPULATION

Adjustment of the controller is accomplished as follows:

1. A standard thermocouple is placed within the control zone of the furnace and the furnace temperature is raised to the desired temperature by means of the main power transformer switches. A portable precision potentiometer is used in conjunction with the standard thermocouple to obtain accurate temperature measurements.

2. Gas is then introduced into the muffle.

3. When the approximate desired temperature has been reached, the sensitivity control in the galvanometer circuit, (B) figure 2, is set at a minimum.

4. The approximate resistance is set on the Helipot, (A) figure 2, for this temperature.

5. Galvanometer unit is adjusted to the mechanical zero point.

6. The Thermocap is allowed to warm up for 15 minutes, then set so that the relays are in the neutral zone portion with galvanometer at mechanical zero.

7. Switch one, figure 2, is closed, placing the galvanometer and thermal sensitive element in operation in the wheatstone bridge. If extreme deflection is obtained on the galvanometer, adjustments must be made to the Helipot so that the resistance is brought into close agreement with the resistance of the thermal sensitive element, thereby obtaining a balance point for the wheatstone

adjustment may be made on the Helipot so that the desired temperature may be maintained. The arrangement discussed under Thermocap Relay on page 4 and Operation on page 5 allows for three different conditions to prevail in the regulation circuit. The voltage variation obtained by these three conditions may be adjusted on the taps of the reactor winding to maintain minimum temperature fluctuations and still allow for maximum stability of the unit.

8. The sensitivity is now increased to a maximum, reducing the width of the neutral zone.

9. The thermocouple is then removed from the furnace and the sample pedestal support inserted in its place in the furnace to the same position. The gas need not be turned off during this operation unless it is being introduced through the bottom of the furnace.

LIMITATIONS

At temperatures near 1400°C the effectiveness of the instrument in maintaining the temperature within the furnace chamber is predicated on the establishment of an unvarying thermal gradient between the thermal sensitive element and the furnace interior. For this reason it is essential that the thermocouple used in standardizing the instrument be surrounded by the same mass of refractory material as the specimen pedestal support used in the operation of the furnace. Figure 1 illustrates the furnace design and operation up to 1500°C. in which periodic readings with a standard thermocouple and portable precision potentiometer of the temperature within the muffle showed deviations of $\pm$ 1°C. over an extended period of time. Voltage fluctuation has very little or no effect on the overall temperature maintained. Ageing of the platinum-rhodium element due to recrystallization and oxidation results in a slow systematic increase in its resistance. This causes a drift to successively lower temperatures. To compensate for this drift the furnace temperature is measured periodically as described above and reset at the proper point. It is

possible to plot the systematic increase in resistance with time at any given temperature and to make quite accurate manual adjustments on the Helipot unit without reintroducing the standard thermocouple.

SUMMARY

A low resistance thermometer temperature controller was constructed which embodies many desirable features for a controlled atmosphere laboratory furnace. No mechanical contacts in the pick-up portion of the apparatus resulted in high sensitivity and nothing to "wear out" through mechanical abrasion. The capacitor pick-up device on the aft end of the galvanometer needle made it possible to maintain temperatures with $\pm$ 1°C. fluctuation up to 1500°C. This work was carried out under contract number N6-ori-143 TO. 1 as a joint undertaking by Alfred University and the Office of Naval Research, with Mr. P. M. Hackett of the Niagara Electron Laboratories.

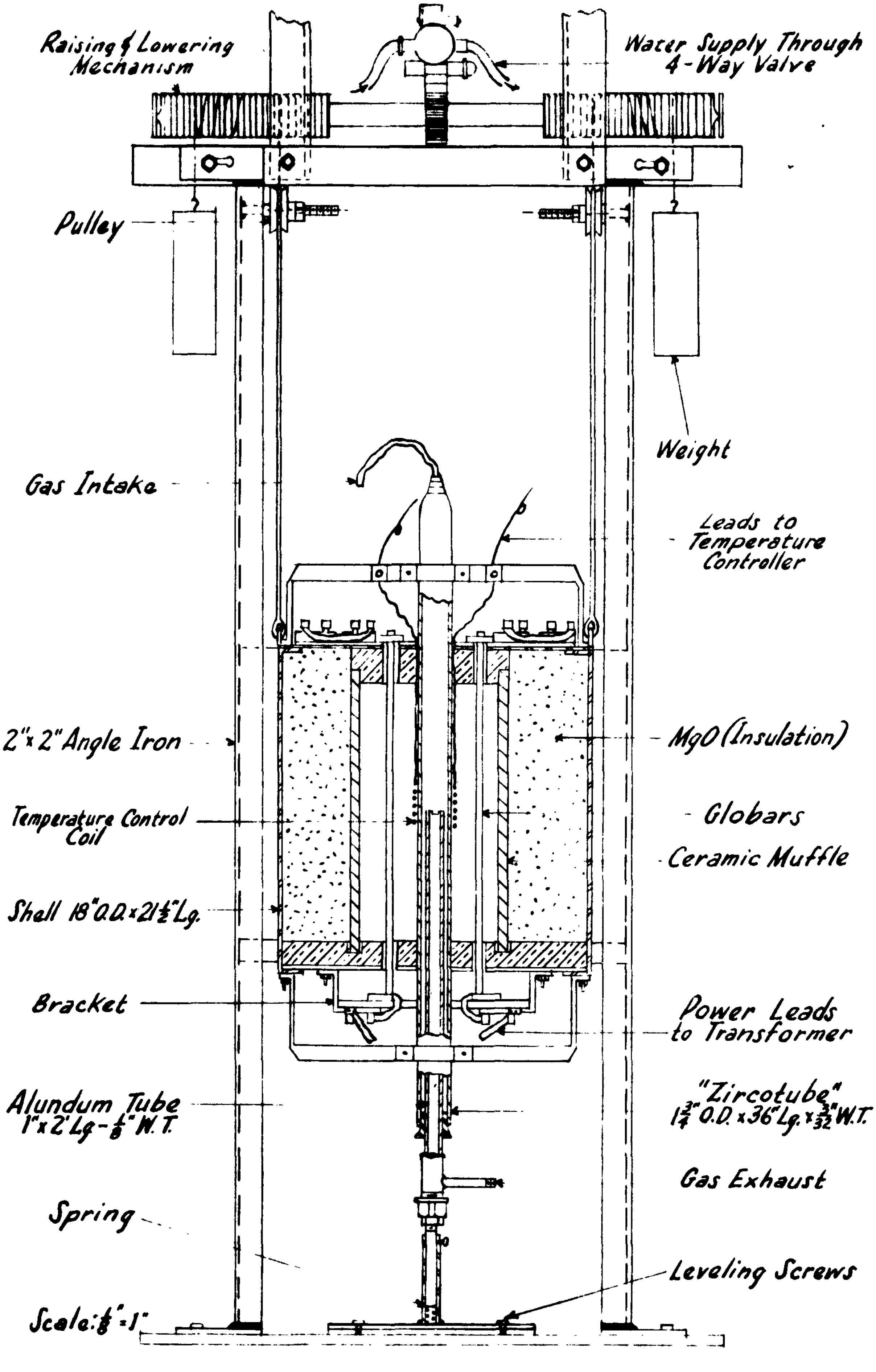

Fig. 1. FURNACE DETAILS

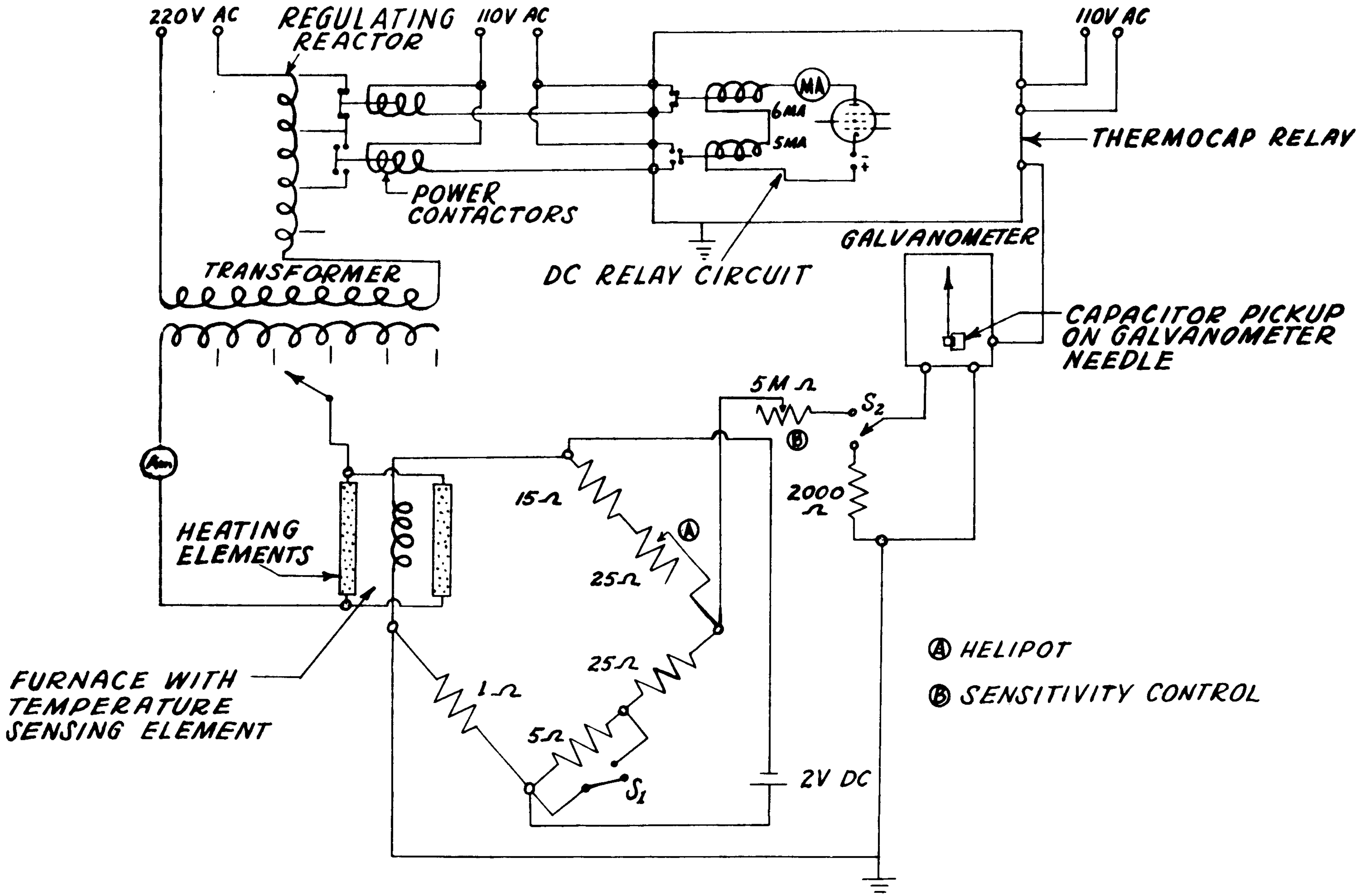

FIG. 2. SCHEMATIC DRAWING OF TEMPERATURE CONTROL CIRCUIT

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